Portable Autonomous Vertical Profiler for Estuarine Applications

Janelle V. Reynolds-Fleming[1,*], Jason G. Fleming[2], and Richard A. Luettich, Jr.[1]

[1] *University of North Carolina at Chapel Hill, Institute of Marine Sciences, 3431 Arendell Street, Morehead City, North Carolina 28557*

[2] *North Carolina State University, Mechanical and Aerospace Engineering, Box 7910, Raleigh, North Carolina 27695*

ABSTRACT: The design and implementation of a portable autonomous vertical profiler are documented and example data sets from a mesotidal estuary and a microtidal, wind-driven estuary are presented. The profiler sampling range dynamically adjusts to changes in water column depth, and a typical vertical sampling resolution of 4 cm is attained. Example data show the onset and vertical and temporal extent of stratification in the water column. The profiler is ideal for water quality monitoring programs in shallow estuaries that require frequent profiles of hydrographic, chemical, and biological parameters that can be measured in situ.

Introduction

The physical, chemical, and biological characteristics of estuaries change in response to external forcing due to the tides, winds, and/or freshwater discharge (Sanford et al. 1990; Simpson et al. 1990; Painchaud et al. 1995; Yin et al. 1995a,b; Savenkoff et al. 1997; Geyer et al. 2000). These temporal changes, which are sometimes rapid, can lead to sharp vertical gradients, i.e., stratification, in the water column. Stratification, usually due to temperature and salinity, serves to isolate portions of the water column and affect concentrations of dissolved gases and contaminants. Water quality monitoring programs are often interested in these concentrations and how they are affected by the development and breakdown of stratification.

Accurate measurements of the onset of stratification and its vertical and temporal extent facilitate the determination of biological and chemical reaction rates in a system. Technological innovations such as water quality multiprobes with increased battery life and memory capacity as well as small data loggers and controllers with advanced programming capabilities and increased data storage have allowed the design of a relatively inexpensive autonomous vertical profiler (AVP) to become a reality. This paper documents the design and implementation of a portable autonomous vertical profiler (P-AVP) for estuarine applications.

An AVP is less expensive and provides higher resolution than deploying a moored vertical array of replicate instruments while reducing the amount of manual labor associated with operation and maintenance. One of the first automated vertical samplers was designed for use in the Chesapeake Bay to monitor water quality conditions around a nuclear power plant (Carter et al. 1978). Honji et al. (1987) designed a self-governing profiling system that moved up and down a mooring line with a vertical resolution of greater than 2 m in deep-water applications. Another profiler, PSWIMS (Luettich et al. 1993), consisted of a sensor mounting bracket that traveled up and down on a threaded rod and four guide poles. The sensor bracket and rod system stopped at a select number of intervals in the water column and was supported by a 2.0-m PVC frame, which limited its applications to shallower and more protected estuarine environments. Purcell et al. (1997) developed a bottom mounted, winch-based vertical profiler that is permanently moored 9 km off the coast of New Jersey in 15 m of water. It was designed to allow a deployment rate of 5 m min^{-1} with a 1-cm vertical resolution. A buoyancy-controlled profiler was designed by researchers from the University of Minnesota (Research Notes 1997). This device is programmed to stop at certain locations within the water column and is accurate to $\pm$ 0.2 m of the requested depth. It has been tested in deep lakes like Lake Michigan. Another deep-water profiling instrument was designed by Doherty et al. (1999) that records conductivity, temperature, depth, and velocity measurements along a mooring wire. Modifications to that system for commercial development are currently underway (Morrison et al. 2000). The oceanographic community is rapidly recognizing the need for and importance of autonomous profilers in both deep water, coastal, and shallow estuarine waters.

The P-AVP design presented here is a good match for the conditions of a shallow estuary. Its

---

* Corresponding author: tele; 252/726-6841 ext. 162; fax: 252/726-2426; e-mail: janelle@email.unc.edu.
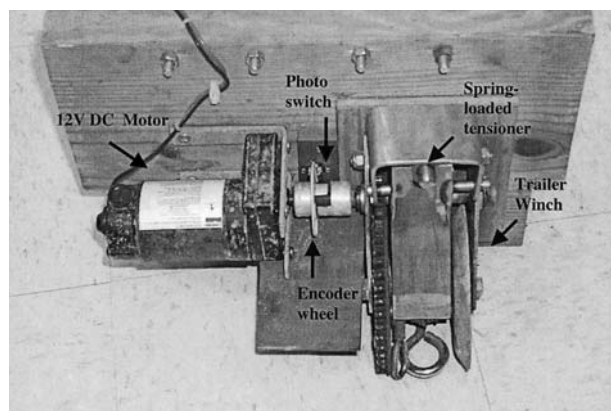
Fig. 1. The top view of the winch assembly package which shows the connections between motor, optical encoder, and winch. A 12 V marine battery supplies power to the 12 V DC motor, which turns both the optical encoder and trailer winch. The optical encoder measures the angular displacement of the winch and the tensioner provides constant tension for a smooth wrap on the drum.

floating design allows easy transport to a desired deployment site, and it may be moored using common anchors such as concrete blocks or diver-deployed screw anchors. It has been deployed in relatively unprotected areas, is designed for autonomous operation, dynamically adjusts the profile range for changes in water depth, has a vertical resolution of 4 cm, and uses a standard, commercially available, multi-parameter water quality probe to collect water quality data during each profile. During warm weather months, the system requires weekly servicing due to bio-fouling of the multi-parameter water quality probe.

Profiling System Design

The core component of the P-AVP is a computer-controlled winch, which unwinds and rewinds cable to the appropriate depth. The P-AVP consists of a computer controlled winch assembly and acoustical altimeter (WAAA), a water resistant housing and deployment platform, and a sensor package comprised of a multi-parameter water quality probe and an external data logger.

Computer Controlled WAAA

The WAAA consists of a standard boat trailer winch (model T1200), a spring loaded tensioner, which helped provide constant tension on the winch spool (fabricated locally by Bircher Machinist), a 102 RPM DC motor (Dayton, model 1L475), a 12 V marine battery, an optical encoder, a digital acoustical altimeter (Datasonics, model PSA-916), and a microcontroller (ONSET Computer Corp., Tattletale model TFX-11).

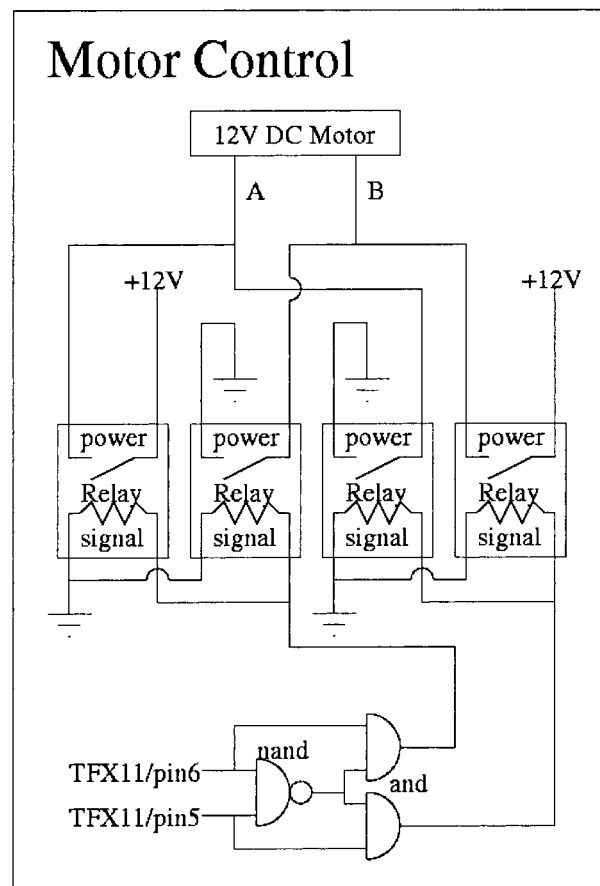The TFX-11 controls power to the acoustical al-

Fig. 2. A Tattletale model TFX-11, the computer controller for the winch assembly and acoustical altimeter (WAAA), controls the distribution of power to the DC motor as shown in this motor control design schematic.

timeter, optical encoder, and DC motor. It also queries the acoustical altimeter to determine the water depth and monitors the optical encoder to determine the angular displacement of the winch (Figs. 1 and 2).

The optical encoder was constructed in our lab and consists of a hand-fabricated encoder wheel and a slotted optical photoswitch (Optek, model OPB830W55). The encoder wheel is a thin plastic disk with two holes around the perimeter (Fig. 3). The wheel is attached to the motor shaft and positioned to allow the edge of the wheel to pass through the photoswitch. The photoswitch is a horseshoe-shaped electronic component with a light emitting diode on one side and a phototransistor (detector) on the other side. If power is supplied to the photoswitch and the detector can see the emitter, the detector output is HIGH. If the detector cannot see the emitter, the detector output is LOW. As the wheel turns, periodic interruptions in the beam, or state transitions, are counted

Optical Encoder
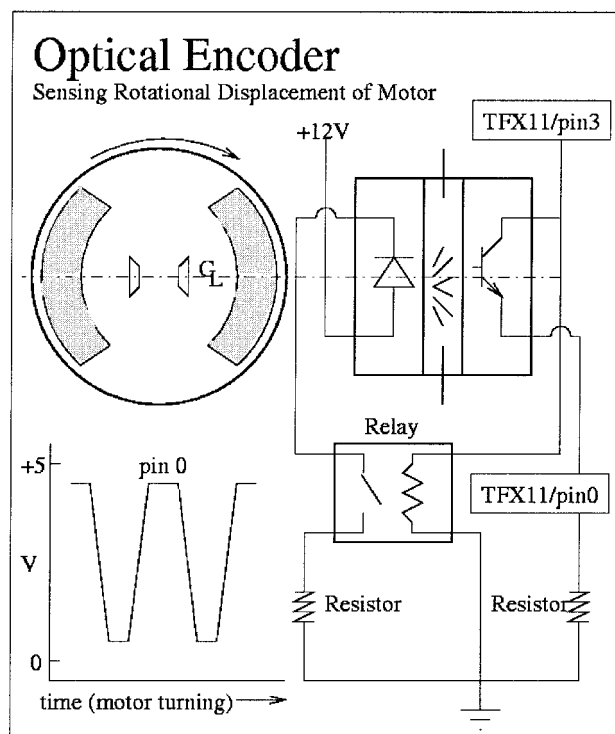### Sensing Rotational Displacement of Motor

Fig. 3.   The schematic of the optical encoder shows a plastic disc with two holes (gray area), which serves as the encoder wheel. The photoswitch detects transitions in the light beam that are counted by the TFX-11 controller and used to determine how much cable has been paid out by the winch.

by the TFX-11. With a winch spool (drum plus cable) diameter of 5 cm and an encoder wheel configured with two holes, vertical position can be resolved to approximately 4 cm.

The TFX-11 has a real time clock, which allows it to perform each profile according to pre-programmed times and duration. When the clock indicates that it is time to start a profile, the TFX-11 switches on power to the motor and optical encoder and raises the sensor package from its parked position to the surface. Upon reaching the surface, the TFX-11 switches off power to the motor and optical encoder and applies power to the acoustical altimeter. The TFX-11 collects an ensemble of depth readings (typically 10) from the altimeter and determines the average water depth. This water depth can be logged by the TFX-11 if desired.

After the depth is determined, the TFX-11 calculates how many optical encoder state transitions are required to lower the sensor package to the bottom, based on the depth measurement and a calibration curve for the relationship between angular displacement of the motor shaft and the linear displacement of the winch cable. We estimate 5–10 cm of uncertainty in this calibration due to

variability in the wrap of the cable on the winch drum. After calculating the number of state transitions, the motor is turned on and lowers the sensor package at a typical speed of 4 cm s^{-1}. When the bottom of the profile is reached, the sensor package is raised back to its parked position near mid-depth.

WATER RESISTANT HOUSING AND DEPLOYMENT PLATFORM

The design of the deployment platform is similar to that of a small floating dock. It is constructed of marine treated lumber and is 1.8×1.8 m with a 0.31×0.31 m hole in the center. Two marine grade floats provide buoyancy for both the platform and instrumentation. The platform is sturdy enough to moor a boat and large enough to hold two average sized adults. Two platforms are easily loaded onto a boat trailer for transport and may be towed into place with a medium sized powerboat.

A water-resistant housing is supported by two pedestals on top of the platform. The WAAA package is raised above the platform to reduce corrosion from sea spray and to allow the sensor package to be brought to the surface for a complete sample of the water column.

The platform can be moored with any convenient means such as concrete anchors or diver-deployed screw anchors. We attached 7.5 m of heavy (2.2 cm) chain to each anchor and 2.54 cm nylon line to each chain. The nylon line is then secured to the corners of the platform so that approximately 1.5 m of chain is off the bottom.

WATER QUALITY PROBE AND EXTERNAL DATA LOGGER

A commercially available multi-parameter water quality probe (Hydrolab Datasonde, model 4a, HD4A) configured with conductivity, pressure, dissolved oxygen (with circulator), and temperature sensors has been used to measure water quality conditions through the water column. We found that the internal data logger that came with the HD4A is not flexible enough to accommodate our sampling schedule and therefore we used a separate, external data logger (ONSET Computer Corp., Tattletale Model 8). The Model 8 and 6 C cell batteries are mounted in a waterproof housing that is strapped to the HD4A (Fig. 4). The HD4A and external data logger housing are shackled to the winch cable and are easily removed for servicing.

The Model 8 has a real time clock that is synchronized with the clock on the TFX-11 and is used to turn the HD4A on and off according to the profiling schedule. When a profile begins, the
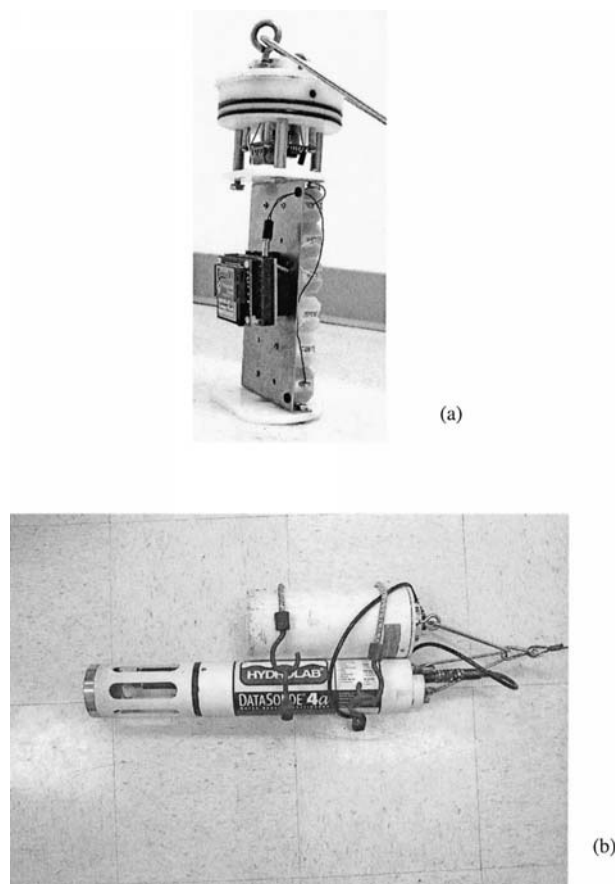
Fig. 4. The water quality sensor package consists of a multi-parameter water quality probe and an external data logger located in a separate waterproof housing. (a) The components associated with the external data logger are 6 C batteries, a Tattletale Model 8 microcomputer, and a compact flash memory card recorder. (b) The multi-parameter water quality probe is strapped to the external data logger housing; a serial data cable connects the two housings. The housings are shackled to a thimble on the end of the winch cable.

Model 8 activates its serial port, which is connected to the HD4A. The HD4A is configured to power itself up and send data at a rate of 1 Hz whenever its serial port is activated. The Model 8 writes the incoming data to a flash memory card (Periperal Issues, model Persistor CF8). When the profile is scheduled to end, the Model 8 turns off its serial port, causing the HD4A to stop sending data and return to a low power mode. Recovering the stored data requires swapping the flash memory card with a fresh card. Based on a typical lowering speed of 4 cm s^{-1} and a 1 Hz sampling rate, profile data is collected at a vertical resolution of 4 cm.

Deployments

The P-AVP minimum sampling depth is limited by the size of the platform floats and the acoustical altimeter. The bottom of the platform floats sit approximately 0.8 m below the water level, while the acoustical altimeter needs a minimum of 1 m water depth in order to obtain good depth readings (Datasonics 1997).

The P-AVP is trailered and towed into position for deployment and attached to its anchors. The Model 8 control program is initialized with the profiling schedule and the water quality probe and external data logger assembly are shackled to the winch cable. The TXF-11 control program is then initialized with the profiling schedule. Servicing frequency is determined primarily by biofouling of the sensors (primarily the dissolved oxygen sensor) on the water quality probe. Servicing is accomplished by lifting the water quality probe and external data logger assembly to the surface, detaching it from the winch cable, replacing the water quality probe with one that has been cleaned and calibrated in the lab, swapping the flash memory card with a fresh one, replacing batteries (if necessary), and re-initializing the profiling schedule in the Model 8 and TXF-11.

To date the P-AVP has been deployed in two different estuarine environments.

Bogue Sound

Bogue Sound is a mesotidal estuary located on the eastern shore of North Carolina (34°43′N, 76°51′W). It has two connections with the Atlantic Ocean: Beaufort Inlet in the east and Bogue Inlet in the west. Water level in the Sound is characterized by a strong semi-diurnal variation due to tidal forcing from the coastal ocean (Peterson et al. 1996). The water velocity reaches approximately 1 m s^{-1} at maximum flood and ebb.

The P-AVP was deployed near the north shore of Bogue Sound for a period of 2 d. It was moored with a two point anchoring system with one side attached to a dock piling and the other side secured with a danforth anchor.

The P-AVP was programmed to collect a profile every 15 min. A comparison between the depth recorded by the acoustical altimeter and the HD4A at its bottom-most position shows good agreement with a mean absolute error of less than 5 cm. The influence of the semi-diurnal tide is seen clearly in the water level data, which indicates a tidal excursion of 60 cm and exemplifies how the P-AVP adjusts to large changes in water level (Fig. 5). The sediment at this location consists of medium to fine sand and produced a strong reflection for the acoustical altimeter.

Contours of dissolved oxygen, salinity, and temperature (Fig. 5) show that the tidal currents are sufficiently strong to vertically mix the water column as there is no indication of stratification in
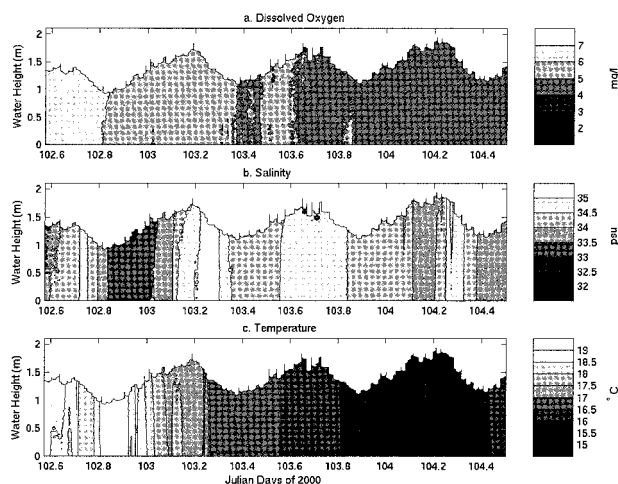
Fig. 5. A well-mixed water column is evident in the contours of dissolved oxygen (a), salinity (b), and temperature (c) for the Bogue Sound deployment in April 2000.
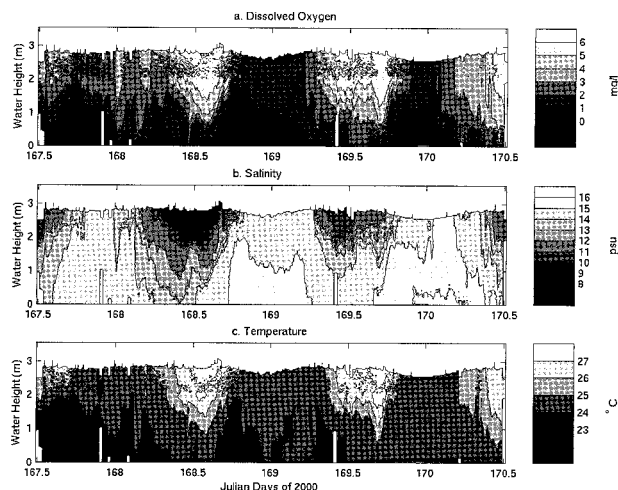

Fig. 6. Strong diurnal stratification is evident in the contours of dissolved oxygen (a), salinity (b), and temperature (c) for a site in the Neuse River estuary in June 2000.

either the salinity or temperature data. Dissolved oxygen data indicate a well-oxygenated water column with values greater than or equal to 5 mg l^{-1}.

NEUSE RIVER ESTUARY

Also located on the eastern shore of North Carolina, the Neuse River Estuary (NRE) is a microtidal estuary (34°58′N, 76°54′W). The NRE is a drowned river valley that averages 4 m deep, 5 km wide, and approximately 70 km long. It empties into the largest lagoonal estuary in the United States, Pamlico Sound. Circulation in the estuary is primarily driven by freshwater discharge, meteorological forcing, and basin-wide seiching with maximum velocities in the range of 0.2 m s^{-1} (Luettich et al. 2000).

The P-AVP was used in an across-channel hydrodynamic and water quality study. Two P-AVPs were deployed near opposite shores of the NRE and collected data from June 12 through September 28, 2000. The TFX-11 was programmed to take a profile every 15 min, which was completed in approximately 5 min. The system was serviced every 4–7 d. For brevity, only results from one site are presented. Figure 6 gives a representative slice of the data from a 3 d time period.

This set of data differs strongly from the Bogue Sound data. The NRE is a mesohaline estuary and rarely experiences salinity values as high as 33‰. Periods of strong stratification as well as well-mixed conditions are identified within this 3-d record. Low dissolved oxygen conditions occur simultaneously with and to the same vertical extent as high salinity water. This suggests that low dissolved oxygen water is advected into the study site rather than generated locally.

Water level in the NRE is highly variable and weather dependent. A wind-driven water level variation as large as 1.5 m has been observed (Luettich et al. 2000). The P-AVP was able to adjust to the variable water depth throughout the course of the 3.5 mo deployment. The acoustical altimeter appeared to perform as well with the muddy substrate of the NRE as with the sandy substrate of Bogue Sound.

Conclusion

The careful design of the P-AVP included minimal custom components and represents a collection of predominately off-the-shelf parts. It has proven itself to be a reliable means of collecting quasi-continuous vertical profiles of standard hydrographic and water quality parameters in shallow estuaries. Its floating design allows easy transport to a desired deployment site and it may be moored using common anchors such as concrete blocks or diver-deployed screw anchors. It has been deployed in relatively unprotected areas, is designed for autonomous operation, dynamically adjusts the profile range for changes in water depth, has a vertical resolution of 4 cm, and uses a standard, commercially available, multi-parameter water quality probe to measure water quality data during each profile. The ability to automatically adjust to different water depths is important in shallow estuaries that experience water level fluctuations that are a significant fraction of the depth. During warm weather months, the system typically requires weekly servicing due to biofouling of the multi-parameter water quality probe (primarily the dissolved oxygen sensor). If biofouling is not an issue, one 12 V marine battery can run the P-AVP for

approximately 2 weeks in deployments such as those described above. Data storage is not a significant limitation since flash memory cards with capacities in excess of a hundred megabytes are now readily available.

The WAAA package is highly adaptable and can be programmed to suit any specific sampling strategy, brand of water quality probe, and water quality probe configuration. Due to variability in the cable wrap on the winch, the winch can position the probe in the water column with an absolute accuracy of 5–10 cm. This error has minimal effect on the profile data since the profiles are re-constructed for plotting and analysis using the depth below the water surface determined from the pressure sensor on the water quality probe. It does suggest a safe distance from the bottom to terminate the profile to keep the water quality probe from coming in contact with the bottom. This safe distance should also take into account wave conditions at the deployment site since vertical platform motion will be translated to the water quality probe. We anticipate that the present P-AVP design can function in up to 20 m water depth with little or no modification.

Presently planned modifications to this P-AVP include the construction of a cage to hold and protect the water quality probe and the external data logger. Our previous experience has indicated that during rough weather these can bang against the platform when they are at the top of a profile. The winch tensioner will be eliminated and replaced with a pulley system that can better control the cable winding on the winch drum. The retrieval of data in real-time can be highly desirable and we are working to incorporate this in the future.

Acknowledgments

Literature Cited

CARTER, H. H., R. J. REGIER, E. W. SCHIEMER, AND J. A. MICHAEL. 1978. The summertime vertical distribution of dissolved oxygen at the Calvert Cliffs Generating Station: A physical interpretation. Chesapeake Bay Institute Special Report 60. The John Hopkins University, Cambridge, Maryland.

DATASONICS, INC. 1997. PSA-916 Sonar Altimeter User's Manual. Datasonics, Inc., Cataumet, Massachusetts.

DOHERTY, K. W., D. E. FRYE, S. P. LIBERATORE, AND J. M. TOOLE. 1999. A moored profiling instrument. *Journal of Atmospheric and Oceanic Technology* 16:1816–1829.

GEYER, W. R., J. Y. TROWBRIDGE, AND M. M. BOWEN. 2000. The dynamics of a partially mixed estuary. *Journal of Physical Oceanography* 30:2035–2048.

HONJI, H., A. KANEKO, AND K. KAWATATE. 1987. Self-governing profiling system. *Continental Shelf Research* 7:1257–1265.

LUETTICH, R. A., W. W. KIRBY-SMITH, AND W. HUNNINGS. 1993. PSWIMS, a profiling instrument system for remote physical and chemical measurements in shallow water. *Estuaries* 16:190–197.

LUETTICH, R. A., J. E. MCNINCH, H. PAERL, C. H. PETERSON, J. T. WELLS, M. ALPERIN, C. S. MARTENS, AND J. L. PICKNEY. 2000. Neuse River estuary modeling and monitoring project stage 1: Hydrography and circulation, water column nutrients and productivity, sedimentary processes and benthic-pelagic coupling, and benthic ecology. Report no. 325-B. Water Resources Research Institute, Raleigh, North Carolina.

MORRISON, A. T., J. D. BILLINGS, K. W. DOHERTY, AND J. M. TOOLE. 2000. The McLane moored profiler: A platform for physical, biological, and chemical oceanographic measurements. Proceedings of the Oceanology International 2000 Conference. March 7–10, 2000, Brighton, UK.

PAINCHAUD, J., D. LEFAIVRE, J. C. THERRIAULT, AND L. LEGENDRE. 1995. Physical processes controlling bacterial distribution and variability in the upper St. Lawrence estuary. *Estuaries* 18:433–444.

PETERSON, C. H., H. C. SUMMERSON, AND R. A. LUETTICH. 1996. Response of bay scallops to spawner transplants. *Marine Ecological Progress Series* 132:93–107.

PURCELL, M., T. AUSTIN, R. STOKEY, C. VON ALT, AND K. PRADA. 1997. A vertical profiling system for making oceanographic measurements in coastal waters, p. 219–224. *In* Proceedings of Oceans 1997 Conference Record. Marine Technology Society, Columbia, Maryland.

RESEARCH NOTES. 1997. Research Notes. *Water Environment and Technology.* 9:75.

SANFORD, L. P., K. G. SELLNER, AND D. L. BREITBURG. 1990. Covariability of dissolved oxygen with physical processes in the summertime Chesapeake Bay. *Journal of Marine Research* 48:567–590.

SAVENKOFF, C., A. F. VÉZINA, AND Y. GRATTON. 1997. Effect of a freshwater pulse on mesoscale circulation and phytoplankton distribution in the lower St. Lawrence estuary. *Journal of Marine Research* 55:353–381.

SIMPSON, J. H., J. BROWN, J. MATTHEW, AND G. ALLEN. 1990. Tidal straining, density currents, and stirring in the control of estuarine stratification. *Estuaries* 13:125–132.

YIN, K., P. J. HARRISON, S. POND, AND R. J. BEAMISH. 1995a. Entrainment of nitrate in the Fraser River estuary and its biological implications. II. Effects of spring vs. neap tides and river discharge. *Estuarine, Coastal and Shelf Science* 40:529–544.

YIN, K., P. J. HARRISON, S. POND, AND R. J. BEAMISH. 1995b. Entrainment of nitrate in the Fraser River estuary and its biological implications. III. Effects of winds. *Estuarine, Coastal and Shelf Science* 40:545–558.